Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations

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SUMMARY

The primary goal of this study was to determine the effectiveness of a planned cockpit rest period to improve alertness and performance in long-haul flight operations. Twenty-one pilots participated and were randomly assigned to either a Rest Group or a No-Rest Group condition. The Rest Group was allowed a planned 40 min. rest period during the low workload, cruise portion of flight. The No-Rest Group had a 40 min. planned control period identified but maintained their usual flight activities during this time.

Several measures were used to examine the physiological, behavioral, performance, and subjective effects of the nap, including continuous ambulatory recordings of brain wave and eye movement activity, a reaction time/vigilance task, and a wrist activity monitor. Subjective measures collected in the study included in-flight fatigue and alertness ratings, a daily log for noting sleep periods, meals, exercise, flight and duty periods, and the NASA Background Questionnaire.

The results indicated that the Rest Group pilots were able to sleep during the cockpit rest period, generally falling asleep quickly and sleeping efficiently. This nap was associated with improved physiological alertness and performance compared to the No-Rest Group. The benefits of the nap were observed through the critical descent and landing phases of flight. The convergence of the behavioral performance data and the physiological data to demonstrate the effectiveness of the cockpit nap lend support to the robustness of the findings. The nap did not affect layover sleep or the cumulative sleep debt displayed by the majority of crewmembers. The nap procedures were implemented with minimal disruption to usual flight operations and there were no reported or identified concerns regarding safety.

The planned nap appeared to provide an effective, acute relief for the sleepiness experienced in nonaugmented 3-person long-haul flight operations. The strength of the current results supports the implementation of planned cockpit sleep opportunities in nonaugmented long-haul flight operations involving 3-person crews. If implemented, we recommend a follow-up study be conducted to examine how planned cockpit sleep opportunities have been incorporated into airline procedures. The results of this follow-up study may lend support for further refinement of procedures and future implementation through Federal regulation.

1.0 OPERATIONAL SUMMARY

This report is the ninth in a series on physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects.

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Long-haul flight operations often involve rapid multiple time-zone changes, sleep disturbances, circadian disruptions, and long, irregular work schedules. These factors can result in fatigue, cumulative sleep loss, decreased alertness, and decreased performance in long-haul flight crews. Thus, operational effectiveness and safety may be compromised because of pilot fatigue. One natural compensatory response to the sleepiness and fatigue experienced in long-haul operations is unplanned, spontaneous napping and non-sanctioned rest periods. That these activities occur is supported by anecdotal, observational, and subjective report data from a variety of sources. In response to this information and to concerns for maintaining flight safety, it was suggested that a planned cockpit rest period could provide a "safety valve" for the fatigue and sleepiness experienced in long-haul flying. The cockpit rest period would allow a planned opportunity to sleep, with the primary goal being to improve subsequent levels of performance and alertness, especially during critical phases of operation such as descent and landing.

This study was co-sponsored and sanctioned by the FAA and involved the voluntary participation of two commercial airlines. The primary goal was to determine the effectiveness of a planned cockpit rest period to improve performance and alertness in nonaugmented, three-person long-haul flight operations. Twenty-one volunteer pilots participated and were randomly assigned to either a rest group (N = 12) or a no-rest group (N = 9) condition. The rest group (RG) was allowed a planned 40 min. rest period during the low-workload, cruise portion of flight over water. Pilots rested one at a time, on a prearranged rotation, with two crewmembers maintaining the flight at all times. The no-rest group (NRG) had a 40 min. planned control period identified during cruise but maintained their usual flight activities during this time. The four consecutive middle legs of a regularly scheduled transpacific trip, part of a 12-day trip pattern, were studied. Two legs were westbound day flights and two legs were eastbound night flights, with generally comparable flight and duty times.

Specific procedural and safety guidelines were successfully implemented in this initial study. However, not all of these would be necessary for a general implementation of planned cockpit rest periods in long-haul flight operations: (1) it was crucial that the rest period was planned, with first choice of rest period going to the landing pilot; (2) the rest periods were scheduled during a low-workload phase of flight and ended 1 hr. before descent; (3) only one crew member was scheduled to rest at a time with a clear planned rotation established; (4) the rest opportunity was divided into an initial preparation period (3 min.), followed by the 40 min. rest period, followed by a recovery period (20 min.) (these times might be altered to reduce the overall length of the period); (5) the rest was terminated at a preset time by a researcher, and the resting pilot was fully briefed before reentering the operational loop; and (6) it was established that the captain would be notified immediately at the first indication of any potential anomaly. The safe and normal operation of the aircraft was given the highest priority and, therefore, no cockpit rest procedure or activity was allowed to interfere with this.

Several measures were used to examine the physiological, behavioral, performance, and subjective effects of the planned cockpit nap. Continuous ambulatory recordings of brain wave and eye movement activity were conducted to determine physiologically how much sleep was obtained during the rest period, as well as the time taken to fall asleep and the stages of sleep. (These recordings allowed differentiation of non-rapid-eye-movement [NREM] sleep and its stages and rapid-eye-movement [REM] sleep). A reaction-time/sustained-attention task (psychomotor vigilance task) was used to assess performance capability. A wrist activity monitor was worn continuously before, during, and after the trip schedule. This activity monitor provided information regarding the pilots' 24 hr. rest/activity pattern and was used to examine layover sleep episodes. Subjective measures collected in the study included in-flight fatigue and alertness ratings, a daily log for noting sleep periods, meals, exercise, flight and duty periods, etc., and the NASA Background Questionnaire.

The physiological data showed that on 93% of the rest period opportunities the RG pilots were able to sleep. Generally, they fell asleep quickly (average = 5.6 min.) and slept for an average of 26 min. There were six factors related to sleep quantity and quality that were analyzed: total sleep time, sleep efficiency, sleep latency, percent NREM stage 1 sleep, percent NREM stage 2 sleep, and percent NREM slow-wave sleep. Each of these factors was examined for effects related to trip leg, halves of the trip, day versus night, and flight position (captain, first officer, second officer).

There were two significant effects that emerged from these analyses. The day flights had significantly more light sleep than night flights, and the night flights had significantly more deep sleep than day flights. An interesting finding emerged from analysis of the physiological data collected during the NRG 40 min. control period. Although instructed to continue usual flight activities, four NRG pilots fell asleep (a total of five episodes) for periods lasting from several minutes to over 10 min.

There were generally consistent findings for the variety of analytical approaches used to examine the performance data. The median sustained attention/reaction time (a performance measure) for the NRG showed a greater range of average responses across flight legs and during in-flight trials than seen in the RG. After leg 1, the pilots in the NRG showed a steady increase in median reaction time across flight legs, with significant differences by the middle and end of flights. The RG pilots maintained a generally consistent level of performance both across and within flight legs, and did not show significant increases in reaction time. There were a total of 283 lapses (i.e., a response delay > 0.5 sec.) for all 21 pilots (both groups combined). For in-flight trials, the NRG (with fewer subjects) had a total of 124 lapses, whereas the RG had a total of 81. There was an increase in lapses during in-flight trials 2 and 3 (after the test period) for the NRG, though this increase did not occur during in-flight trials following the nap in the RG. Both groups had more lapses before top of descent (TOD) on night-flight leg 4 than on night leg 2. However, the number of lapses in the NRG pilots increased twice as much as in the RG pilots. Vigilance decrement functions also revealed that on night flights the NRG pilots had a level of performance that was significantly decreased relative to the RG pilots. Generally, the performance task demonstrated decrements across flight legs and within flights for the NRG, whereas the RG maintained consistent levels of performance. These findings suggest that the planned nap prevented deterioration of vigilance performance.

Changes in brain wave and eye movement activity can reflect the subtle ways that physiological alertness/sleepiness changes. An intensive critical phase analysis was conducted to examine the effects of the cockpit nap on subsequent physiological alertness. The period from 1 hr. before TOD through descent and landing was analyzed for the occurrence of brain and eye movement microevents indicative of reduced physiological alertness. During approximately the last 90 min. of flight, each event greater than 5-sec. duration was scored for both the NRG and RG. There was at least one such microevent identified in 78% of the NRG and 50% of the RG. Overall, there were a total of 120 microevents that occurred in the NRG (with fewer subjects) and a total of 34 microevents in the RG. The NRG averaged significantly more total microevents (6.37) than the average in the RG (2.90). This supports the conclusion that the sleep obtained during the rest period was followed by increased physiological alertness in the RG relative to the NRG.

The 24 hr. rest/activity patterns, in combination with the subjective logs, demonstrated that 86% of the 21 subjects accumulated a sleep debt that ranged from 4 to 22 hr. and averaged approximately 9 hr. by the ninth day of the duty cycle. When the entire 36 hr. duty period (layover and subsequent duty cycle) is considered, the percent of layover sleep time is 28%. This is less than the average 33% sleep time spent off-duty at home, hence the cumulative sleep debt. One subject gained sleep, and two others had no change. Further analysis demonstrated that the cockpit nap did not significantly alter the cumulative sleep debt observed in the RG. Also, 77% of the layovers involved more than one sleep episode. Generally, there were two sleep episodes, and if the first one was long, then the second one was short or did not occur. Conversely, if the first sleep episode was short, then there was almost always a second one that was long. This result demonstrated that there were multiple factors operating to control sleep timing and quantity (e.g., local time, home circadian time, prior sleep loss). This study was not designed to examine the issue of layover sleep periods, though recently the timing of layover sleep periods, including naps, in long-haul flight operations has been addressed.

Overall, the analysis of the subjective alertness ratings demonstrated that pilots reported lower alertness on night flights than on day flights and after the rest/control period than before it (except on leg 1). The results indicated that the nap did not affect the subjective ratings of alertness, though the objective measures clearly indicated better performance and greater alertness in the RG. The level of physiological sleepiness experienced in long-haul flight operations was demonstrated in both subject groups. The speed of falling asleep has been used as a measure of physiological sleepiness (i.e., the more sleepy an individual, the faster he or she will fall asleep). The speed of falling asleep in the RG (5.6 min.) is comparable to that seen in moderately sleep deprived individuals. A diagnostic guide for excessive sleepiness in sleep disorder patients is a sleep latency of 5 min. or less. Also, there were five episodes of sleep that occurred during the control period in four NRG pilots who had been instructed to continue usual flight operations. This result reinforces previous findings that pilots are poor evaluators of their level of physiological sleepiness.

Overall, the study results provide support for differentiating fatigue countermeasures into two basic approaches. Conceptually and operationally, methods to minimize or mitigate the effects of sleep loss, circadian disruption, and fatigue in flight operations, can be divided into (1) preventive strategies and (2) operational countermeasures. Preventive strategies involve those approaches that result in more long-term adjustments and effects on underlying physiological sleep and circadian processes (e.g., possibilities for further research include shifting the circadian phase before multiple time-zone changes, using bright lights or exercise to rapidly readjust the circadian clock, and maximizing the quantity and quality of sleep). These preventive strategies affect underlying physiological sleep need, sleepiness, and circadian phase in a long-term and chronic fashion. Operational countermeasures are focused strategies for reducing sleepiness and improving performance and alertness during actual operations (e.g., proved strategies include judicious use of caffeine, increased physical activity, and increased interaction). These short-acting countermeasures are not intended to reduce underlying physiological sleepiness or a sleep debt, but rather to increase performance and alertness during operational tasks. One acute, short-acting operational countermeasure that can temporarily reduce physiological sleepiness is napping. The planned cockpit nap in this study is considered to be an operational countermeasure that provided an acute, short-acting improvement in performance and alertness.

It must be acknowledged that every scientific study has specific limitations that restrict the generalizability of the results. This study involved only one trip pattern on a commercial airline carrier. The study was conducted on transpacific flights to utilize the opportunity of scheduling the planned rest periods during the low-workload portion of cruise over water. The intense physiological and performance data collection occurred during a specific and restricted middle segment (four consecutive flight legs) of the trip schedule. Therefore, the initial home-to-flight-schedule transition is quantified only with logbook and activity data. Also, the highest levels of accumulated fatigue, which probably occurred during the final trip legs, were not studied except for logbook and activity data. This study involved B-747 aircraft flown by three-person crews; the specific application of this countermeasure to the two-person cockpit was not addressed.

There were two NASA researchers on the flight deck during the in-flight data collection periods. Although they were instructed to minimize their interactions and presence, there is no question that having two extra individuals on the flight deck may have potentially altered the regular flow of cockpit conversation and interaction. It is important to remain cognizant of these limitations when attempts are made to generalize the study results to questions that extend beyond the scope of the specific scientific issues addressed here.

In conclusion, the RG pilots were able to sleep during the planned cockpit rest period, generally falling asleep quickly and sleeping efficiently. This nap was associated with improved performance and physiological alertness in the RG compared to the NRG. The benefits of the nap were observed through the critical descent and landing phases of flight. The convergence of the behavioral performance data and the physiological data to demonstrate the effectiveness of the cockpit nap lend support to the robustness of the findings. The nap did not affect layover sleep or the overall cumulative sleep debt displayed by the most of the crewmembers. The nap procedures were implemented with minimal disruption to usual flight operations, and there were no reported or identified concerns regarding safety.

The planned nap appeared to provide an effective, acute relief for the fatigue and sleepiness experienced in nonaugmented three-person long-haul flight operations. The strength of the current results supports the implementation of planned cockpit sleep opportunities in nonaugmented long-haul flight operations involving three-person crews. If planned cockpit sleep opportunities were sanctioned, each airline could determine the appropriate incorporation of procedures into its specific mode of operation. If implemented, we recommend that a joint NASA/FAA follow-up study be conducted within 6-12 months to examine how planned cockpit sleep opportunities have been incorporated into airline procedures. That study would examine how the procedures were implemented and their effectiveness. This might take the form of a survey or include some field data collection. The results of that follow-up study might then lend support for further refinement of procedures and future implementation in other flight environments.

2.0 INTRODUCTION

2.1 Background

The rapid multiple time-zone changes, sleep disturbances, circadian disruptions, and long, irregular work schedules associated with long-haul flight operations can result in pilot fatigue. Safety and operational effectiveness during long-haul flights may be compromised because of reduced pilot performance and alertness. Pilot fatigue in long-haul flight operations is a major safety concern.

Several sources lend support to this concern. Long-haul wide-body flight operations have almost a three-times higher loss ratio than combined short- and medium-range flights (ref. 1). Also, cockpit crew error, where pilot fatigue may be a contributory factor, has been related to 75% of aircraft losses since 1959 (ref. 1). NASA's Aviation Safety Reporting System (ASRS) receives reports every month from long-haul crews describing the role of fatigue, sleep loss, and sleepiness in significant operational errors. Reported errors have included altitude deviations, improper fuel calculations, track deviations, landings without clearance, and landings on incorrect runways. These reports are not surprising, for many pilots describe anecdotally the overwhelming fatigue and sleepiness associated with all-night flying over the ocean. The flight deck environment, with constant background noise, dim lighting, and various levels of automation, can contribute to the difficulty of remaining vigilant and awake under these circumstances. As trips progress and as the number of flight legs increases, so too can the cumulative effects of sleep loss and fatigue.

Extensive research has shown that there are at least three interrelated biological sources of the fatigue, sleep loss, and sleepiness experienced in long-haul flight operations (e.g., refs. 2-4): (1) circadian disruption, (2) cumulative sleep loss, and (3) sleepiness rhythm. Each of these factors will be reviewed briefly to provide greater understanding and background for the causes of fatigue and sleepiness in long-haul flying.

Human circadian (i.e., about 24 hr.) rhythms are internally controlled by a biological clock in the brain. There are many examples of biological functions that fluctuate over a 24 hr. period, such as sleep and wakefulness, body temperature, and activity. Transmeridian flights rapidly transport this internal human circadian clock to new external time zones. The internal biological clock, however, is unable to adapt quickly and instead adjusts to the new external time zone at a slow rate. The result is a desynchrony between biological rhythms and external synchronizers (e.g., light, meals) and a disorganization of internal physiological and psychological rhythms as the circadian clock slowly adjusts to the new environmental time. Most pilots are familiar with these factors as primary causes of their experience of fatigue and other symptoms of jet lag. It has been shown that the severity of circadian adjustment effects is related to the number of time zones crossed. The more time zones crossed, the greater the adjustment required by the circadian clock. It is also known that there are wide individual differences in ability to adjust to new time zones. Some individuals can experience severe effects following a time-zone change of only 1 or 2 hr.

One basic biological property of the human circadian clock accounts for the generally familiar experience of easier and faster adjustment when flying west than when flying east. If allowed to run at its natural rhythm, the average internal biological clock would actually have a cycle slightly longer than our 24 hr. day, about 25 hr. This means that there is a natural, inherent tendency to lengthen our day. Therefore, when traveling a westward, the circadian day is lengthened (or delayed) and promotes adjustment to the new time zone. Conversely, when flying eastward the